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CO-EVOLUTIONARY COUPLING BETWEEN CAPTURED AND UNCAPTURED GDP CYCLES: CROSS LEARNING FROM AMAZON AND FINLAND MODELS FOR SUSTAINABILITY

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ABSTRACT

A solution to the critical problem of a dilemma between R&D expansion and productivity decline that a majority of information and communication technology (ICT) leaders have been confronting in the digital economy is expected. It can be expected by a spinoff from economic functionality-seeking GDP-based co-evolution cycle to supra-functionality beyond an economic value-seeking uncaptured GDP-driven co-evolution cycle. However, the transformation dynamism remains a black box.

By means of numerical simulations based on empirical analyses of the development trajectories of global ICT leaders, focusing on Amazon and Finland, together with an intensive review of preceding analyses, this paper attempted to elucidate the inside the black box of the above dynamism.

By developing a practically applicable numerical approach, inspired attempts to explore a new elucidation frontier were conducted, thereby enabling a new concept of co-evolutionary coupling between two cycles to be postulated.

An insightful suggestion regarding possible consequences in the future stemming from the trajectory option was thus provided.

KEYWORDS

Co-evolutionary coupling, uncaptured GDP, transformation, Amazon and Finland, dilemma between R&D and productivity

1. INTRODUCTION

Notwithstanding the critical problem of a dilemma between R&D expansion and productivity decline that a majority of information and communication technology (ICT) leaders have been confronting in the digital economy [1, 2], Amazon has been able to accomplish a skyrocketing increase in R&D and subsequent market capitalization as demonstrated in **Fig. 1** [3].

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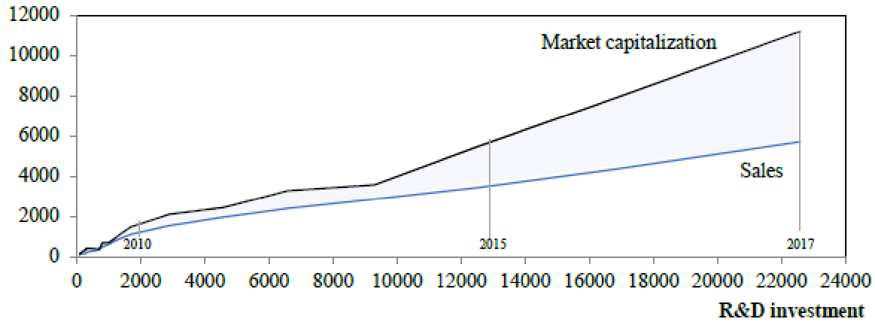


Figure 1. The Correlation between R&D investment and sales as well as market capitalization in Amazon (2001-2017) – Index: 2001 = 100.

Source: [4].

Finland, one of the ICT leader in the world, has also accomplished balanced advancement not only of welfare but also economic growth by means of a notable resurgence as demonstrated in **Fig. 2** [5].

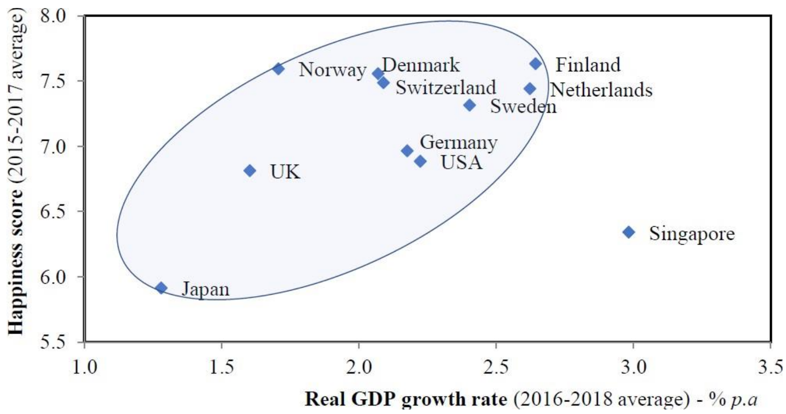


Figure 2. Comparison of balanced development of economic growth and happiness in 11 leading countries. Sources: [6, 7].

The sources of both successes can be attributed to harnessing the vigor of soft innovation resources (*SIRs*) from the marketplace, thereby both demonstrates notable breakthrough beyond economic values. However, contrary to Amazon's complementary use of *SIRs*, Finland has depended on substitutionary use. While Finland's approach contributes to easy resurgence, it casts a shadow to the innovative growth in the future [8]. IMF has published reserved prospect of GDP growth toward 2023 [6]. This forecast sounds the alarm that Finland's way of transformation may result in canceling its notable resurgence.

The above contrast can be attributed to the difference of the trajectory option in transforming the captured GDP-based co-evolution cycle and the uncaptured GDP-driven co-evolution cycle in the digital economy.

The authors in previous studies stressed the significance of increasing dependence on the uncaptured GDP by postulating that the Internet promotes a free culture that provides utility and happiness to people but cannot be captured through GDP. This added value of providing people with utility and happiness, which extends beyond economic value, is defined as uncaptured GDP [9, 10].

The shift in people's preferences from the economic value to the supra-functionality beyond an economic value (encompassing social, cultural, and emotional values) [11] induces the further advancement of the Internet, which intensifies the increasing dependence on uncaptured GDP.
Thus, spinoff from traditional co-evolution among traditional ICT, captured GDP, and economic functionality to new co-evolution among the advancement of the Internet, the increasing dependence on uncaptured GDP, and people's shifting preferences to beyond an economic value has been accelerated as illustrated in **Fig. 3** [9, 10, 12-14].

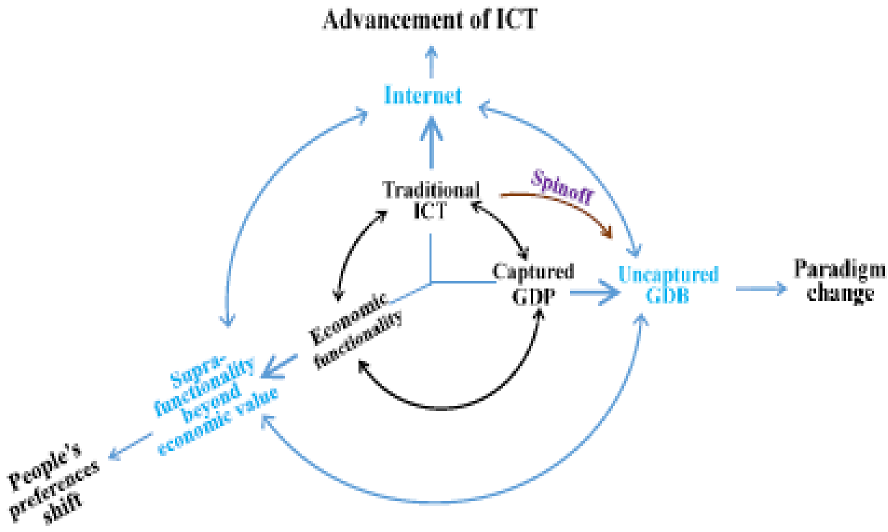


Figure 3. Spinoff dynamism from the captured GDP-based co-evolution to the uncaptured GDP-driven co-evolution.

Therefore, this spinoff dynamism plays a decisive role in development trajectory towards the robust sustainable growth in the digital economy.

While a increasing number of studies have attempted to analyze this dynamism (e.g., [15, 16]) none has elucidated the inside the blackbox of this dynamism from the view point of possible consequences of the development trajectory options.

Sussan et al. [17] and Gestrin et al. [18] are invaluable exceptions. They attempted to identify the transformation from non-digital state to the digitalizing state by analyzing the process of becoming increasingly digital economy. Their attempts provide inspiring suggestions for practical analysis of this transformation dynamism.

By means of numerical simulations based on the empirical analyses of the development trajectories of the global ICT leaders, together with an intensive review of preceding analyses, this paper attempted to elucidate this dynamism. By developing the practically applicable numerical approach, inspiring attempts to explore the new elucidation frontier were conducted.
An insightful suggestion with respect to the possible consequences in the future stemmed from the trajectory option was thus provided.

Organization of this paper is as follows: Section 2 over reviews consequences of the ICT-driven development trajectory. Transformation dynamism is examined in Section 3. Section 4 discusses cross learning from Amazon and Finland. Section 5 summarizes the noteworthy findings, policy suggestions, and future research.

2. Consequences of the ICT-Driven Development Trajectory

2.1. Fatality of Unique Feature of ICT

Given the ICT-driven development, its growth follows a sigmoid trajectory (see *Note*) which continues to grow until it reaches carrying capacity (upper limit of growth) as illustrated in the top of **Fig. 4**. In this trajectory, while growth rate continues to increase before reaching to the inflection point corresponding to the half level of carrying capacity, it changes to decrease after exceeding the inflection point. Thus, ICT-driven logistic growth incorporates bi-polarization fatality, increase and decrease of marginal productivity between before and after the inflection point as illustrated in the middle of Fig. 4. This causes the dilemma between R&D expansion and productivity decline as R&D expansion (which is essential for competition) results in productivity decline and subsequent growth rate decrease.

Confronting such a dilemma, global ICT-leaders have been endeavoring to find a practical solution by transforming their traditional business model into a new business model.
Given that this dilemma stems from the unique feature of ICT, logistic growth, this feature should be transformed.

As far as the development trajectory depends on the simple logistic growth (*SLG*) trajectory, its digital value, $V_s(R)$, saturates with the fixed upper limit which inevitably results in the above dilemma. However, once the trajectory shifts to logistic growth within the dynamic carryingcapacity (*LGDCC*), its digital value, $V_L(R)$ can continue to increase as it creates new carrying capacity during the process of development as illustrated in the bottom of **Fig. 4**.

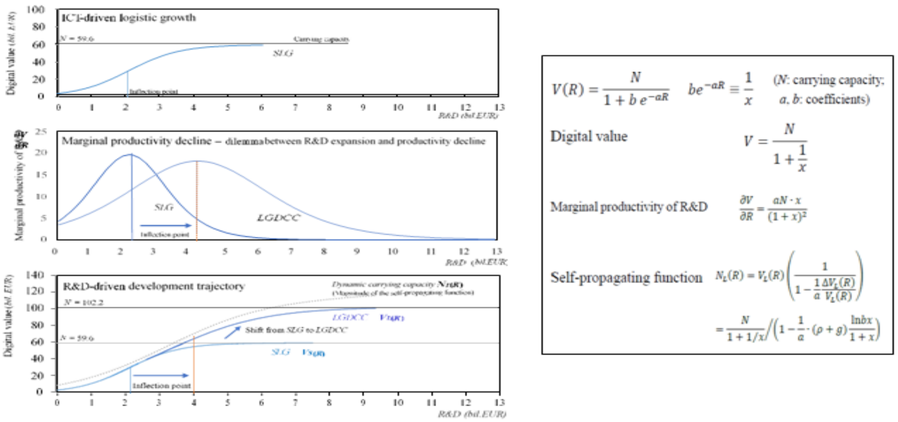


Figure 4. Dynamism in overcoming the dilemma in global ICT firms (2016).

Numbers of analyses of the innovation diffusion were conducted since after the invention of the epidemic function by Verhulst in 1845.

Based on these preceding works, this paper attempted to develop and apply a practical approach supportive to elucidate the inside the blackbox of transformation from the captured GDP-based co-evolution cycle into the un- captured GDP-driven co-evolution cycle.

Note: ICT in which network externalities function to alter the correlation between innovations and institutional systems which creates new features of the innovation leading to exponential increase [19]. Schelling [20] portrayed an array of logistically developing and diffusing social mechanisms stimulated by these interactions. Advancement of the Internet further stimulates these interactions and accelerates ICT's logistically developing and diffusing feature which is typically traced by the sigmoid curve.

Creation of new carrying capacity is induced as a repulsive power of price (marginal productivity) decrease as a consequence of the bi-polarization fatality against the excessive R&D as illustrated in the middle of Fig. 4. This repulsive power enforces ICT leaders absorb resources for innovation particularly of soft innovation resources (*SIRs*) from the external market that advances innovation without confronting the dilemma, and assimilate them in their business [3]. Here, *SIRs* are considered as a condensate and crystal of the advancement of the Internet [1, 2] and consist of the Internet based resources that have been either sleeping or untapped or are results of multisided interaction in the markets where consumer is looking for functionality beyond an economic value.
Assimilated *SIRs* awake and activate latent self-propagating function indigenous to ICT. Activated self-propagating function induces functionality development leading to exploring supra-functionality beyond an economic value as also illustrated in the bottom of Fig. 4. Since this functionality corresponds to people's preferences shift in the digital economy, digital value increases in response to people's increasing demand. Thus, ICT leaders can maintain sustainable growth by overcoming the dilemma.

During the process of this sustainable growth endeavor, ICT leaders' development trajectory is transformed from the traditional GDP-based co-evolution cycle to the uncaptured GDP-driven co-evolution cycle as illustrated in the upper double circle in **Fig. 5** [9, 10, 12-14].

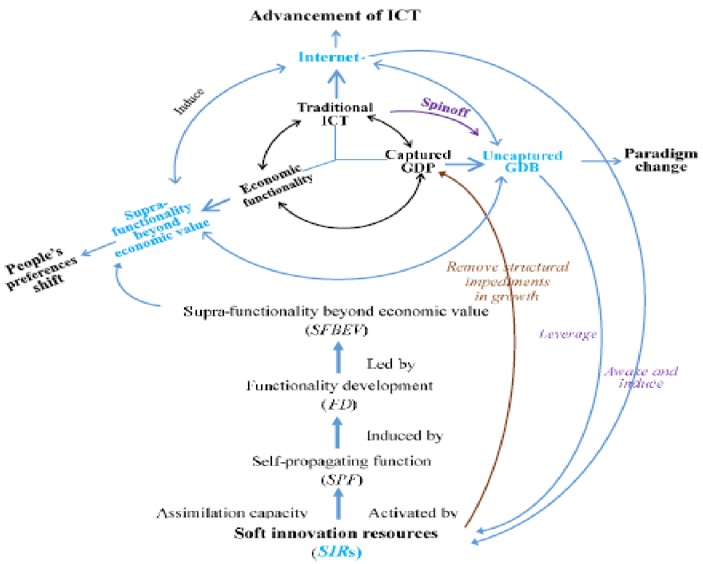


Figure 5. The disruptive business model initiated by global ICT leaders.

The shift in people's preferences from the economic value to the supra- functionality beyond an economic value (encompassing social, cultural, and emotional values) induces the further advancement of the Internet, which intensifies the increasing dependence on uncaptured GDP.

Thus, spinoff from co-evolution among traditional ICT, captured GDP, and economic functionality to new co-evolution among the advancement of the Internet, the increasing dependence on uncaptured GDP, and people's shifting preferences to beyond an economic value has been accelerated as illustrated also in the upper double circle in Fig. 5 [9, 10, 12].

These analyses demonstrate the significance of the ability enabling a smooth transformation from the traditional captured GDP-based co-evolution cycle to the uncaptured GDP-driven co-evolution cycle. This ability corresponds to the ability of conceptualizing intangible values that satisfy consumers' utility in an Internet of Things (IoT) society and also of accepting transformation of captured GDP into uncaptured GDP, thereby mutual coupling can be expected.

This ability largely depends on the ability of absorb *SIRs* from the marketplace and assimilate them in own business. Amazon has developed ability to enclose customers, thereby conceptualized its intangible value [21].

This conceptualization corresponds to transformation of the captured GDP-based co-evolution cycle into the uncaptured GDP-driven co-evolution cycle leading to gross GDP increase.

While this could result in new monopoly, such monopoly should be avoided by developing strong competitive powers, not regulating neither dividing winners. Amazon's R&D model transforming "product" focusing on routine or periodic alteration endeavors into "technology" that contributes to significant improvement should be appraised in this context [2].

2.2. Self-Propagating Function

Given the incorporation of the above ability that enables the smooth transformation, the *LGDCC* explores the self-propagating function that enhances the upper limit of the development trajectory dynamically as growth proceeds as reviewed in the bottom of Fig. 4.

Thus, contrary to the *SLG* that is pressed against its development trajectory by fixed carrying capacity N, the *LGDCC* incorporates a dynamic carrying capacity $N_L(R)$ that rises dynamically as development proceeds. With this dynamic carrying capacity, its digital value $V_L(R)$ can be depicted by the following epidemic function (see the details of the mathematical demonstration in Appendix 2):

$$\frac{dV_L(R)}{dR} = aV_L(R)\left(1-\frac{V_L(R)}{N_L(R)}\right) \tag{1}$$

Therefore, the dynamic carrying capacity identical to the *LGDCC* and represents the magnitude of the self-propagating function can be depicted by the following equation as a function of the growth rate of the digital value in transformation ($\Delta V_L(R)/V_L(R)$):

$$N_L(R) = V_L(R)\left(\frac{1}{1-\frac{1}{a}\frac{\Delta V_L(R)}{V_L(R)}}\right) \qquad \Delta V_L(R) = \frac{dV_L(R)}{dR} \tag{2}$$

As demonstrated in Fig. 5, this self-propagating function is activated by *SIRs*. With this understanding, and also understanding that *SIRs* are considered condensates and crystals of the Internet [2], the authors demonstrated that the self-propagating function measured by the above equation behaves a reasonable performance corresponding to the above analyses as summarized in **Table 1** [1, 2, 22]:

Table 1. The correlation between *SIRs* and the self-propagating function in UPM (1995-2017).

$$\ln N_L(R) = \underset{(109.79)}{2.973} + \underset{(11.30)}{0.362}\, D_1 \ln ID + \underset{(21.51)}{0.424}\, D_2 \ln ID + \underset{(32.91)}{0.536}\, D_3 \ln ID \qquad adj.\ R^2\ 0.985 \quad DW\ 1.20$$

$N_L(R)$: Self-propagating function; ID: Internet dependence; D: Dummy variables

D_1: 1995 – 2002 = 1, others = 0 ; D_2: 2003 – 2007 = 1, others = 0; D_3: 2008 – 2017 = 1, others = 0

UPM is a world circular economy leader in Finland; *ID* is used for a proxy of *SIRs* (Watanabe et al., 2018*c*).

The figures in parentheses indicate the t-statistics: all are significant at the 1% level.

The above analyses demonstrate the new disruptive business model initiated by the global ICT leaders for increasing functionality development by exploring and utilizing external resources that arouse and activate the latent self-propagating function indigenous to ICT as illustrated in Fig. 5. Thus, activation of a latent self-propagating function indigenous to ICT through growth is a key to overcome the dilemma as illustrates in **Fig. 6**.

Self-propagating function

$$N_L(R) = V_L(R)\left(\frac{1}{1-\frac{1}{a}\cdot\frac{\triangle V_L(R)}{V_L(R)}}\right) \qquad \triangle V_L(R) = \frac{dV_L(R)}{dT}$$

Growth rate

Marginal productivity of R&D — R&D intensity

$$\frac{\Delta V_L(R)}{V_L(R)} = \frac{\partial V_L(R)}{\partial T}\cdot\frac{T}{V_L(R)}\cdot\frac{\Delta T}{T} \approx \frac{\partial V_L(R)}{\partial T}\cdot\frac{R}{V_L(R)} = (\rho+g)\cdot\frac{\partial V_L(R)}{\partial R}\cdot\frac{R}{V_L(R)}$$

Figure 6. Dynamism in activating latent self-propagating function.

2.3. Dynamism in Activating the Self-propagating Function

Fig. 6 demonstrates that explicit growth by means of an increase of a product of marginal productivity of technology and R&D intensity should be essential to activate self-propagating function indispensable for shifting from a *SLG* to a *LGDCC* trajectory that overcomes the dilemma. For that, fundamental features of the *LGDCC* should be realized. As demonstrated in **Fig. 7**, the *LGDCC* allows higher R&D before changing to marginal productivity of technology decline, and this productivity shifts to lower level as the *LGDCC* function increases (see the details of the empirical demonstration in Appendix 2).

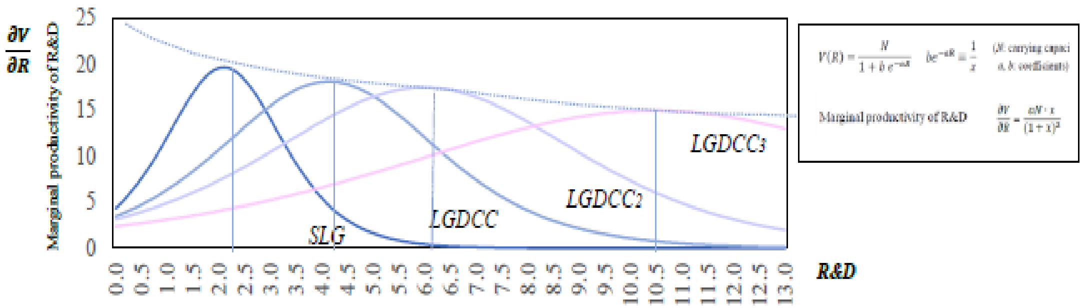


Figure 7. Dynamism enabling higher R&D without the dilemma.
Original source: [8].

Looking at Fig. 7 we note that while the *LGDCC* enables higher R&D before changing to marginal productivity of technology decline, this productivity shifts to lower level as the *LGDCC* function increases. With these findings, if we look back again Fig. 6, it is evident that R&D intensity increase plays a key role in activating latent self-propagating function indigenous to ICT and indispensable to shifting to a *LGDCC* which solves the dilemma.

However, it should be noted that while the *LGDCC* enables higher R&D without productivity decline, it also cannot avoid confronting this decline by depending excessive R&D. This suggests the significance of harnessing the innovation resources from the external market. The authors in the preceding studies demonstrated the significance of neo open innovation that harness the vigor of *SIRs* from the marketplace as illustrated in Fig. 5 [1, 2]. They demonstrated that effective utilization of these resources depends largely on the assimilation capacity that absorbs these resources from the marketplace and assimilate them into own business.

This capacity depends on a rapid and notable increase in R&D as Amazon has demonstrated [3]. This scheme is illustrated in **Fig. 8.**

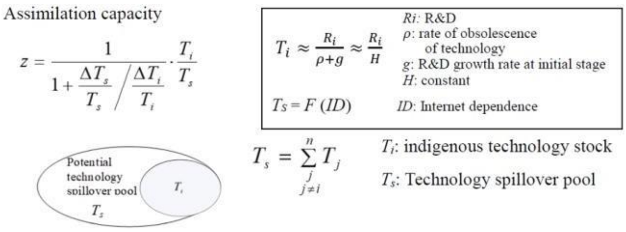


Figure 8. Scheme of measuring dynamic assimilation capacity.

Source: [23].

3. Transformation Dynamism

Core Function of Disruptive Business Model

The above analyses suggest a dynamism of a core function of the disruptive business model that overcome the dilemma between R&D expansion and productivity decline as illustrated in **Fig. 9**.

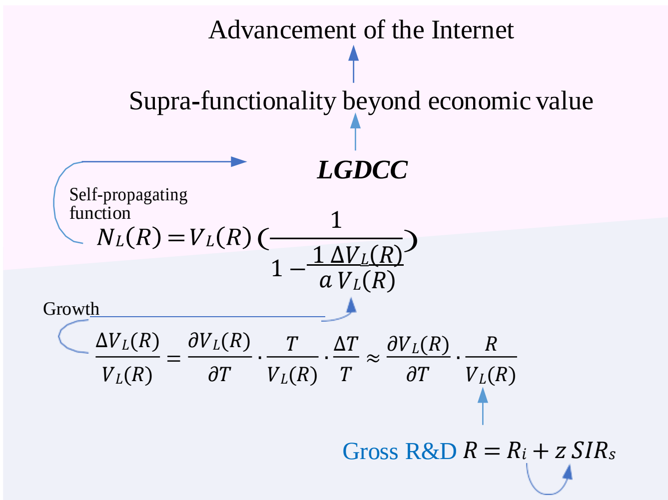


Figure 9. Dynamism of a core function of the disruptive business model.

*[1]: *LGDCC* enables higher R&D before changing to marginal productivity decline (see Fig. 7).
*[2]: Assimilation capacity depends on the rapid and notable R&D increase (see Fig. 8).

Core function is to activate the latent self-propagating function through growth by means of increase in gross R&D increase consisting of increases in indigenous R&D (R_i) and assimilated external innovation resources centered on *SIRs*. Increased gross R&D contributes to growth thereby activates the latent self-propagating function.

In this self-propagating function activation process, the latent functions of digitalization centered on digital technologies awake and start full-fledged operation leading to broad adoption and diffusion of these functions in broad socio-economic and institutional systems towards an IoT society. Such broad adoption and diffusion that leverages a transformation of non-digital state into increasingly digital state enhance the dynamic carrying capacity of the *LGDCC* ($N_L(R)$). This enhancement accelerates a shift to the *LGDCC* as illustrated in Fig. 4. This shift induces functionality development successively, leading to supra-functionality beyond an economic value.

Here, digital economy refers to the broader economy as it undergoes the process of becoming increasingly digital, while digitalization involves the conversion of things (sound, shapes, information, etc.) into digital data, which can be infinitely (re) processed and stored at negligible marginal cost [18], which corresponds to uncaptured GDP dependence. While digitization is the technical process, digitalization is a socio-technological process of applying digitization techniques to broader social and institutional contexts that render digital technologies infrastructure [17].

Thus, leveraged by this activated latent digitalization function, development trajectory transforms from captured GDP-based co-evolution cycle (indicate in light blue) to uncaptured GDP-driven co-evolution cycle (similarly in pink). This transformation can be attributed to the inertia of people's preferences shift and also the Internet function to create new functionality corresponding to such shift.

Fig. 10 and **Table 2** demonstrate this transformation in Amazon. Amazon has accelerated its digitalization by migrating all retail web services to Amazon Web Service (AWS) in 2010 thereby shifted to increasingly digital state [3]. Conspicuous increase in market capitalization exceeding largely the pace of sales increase since then demonstrates the transformation into increasingly digital state.

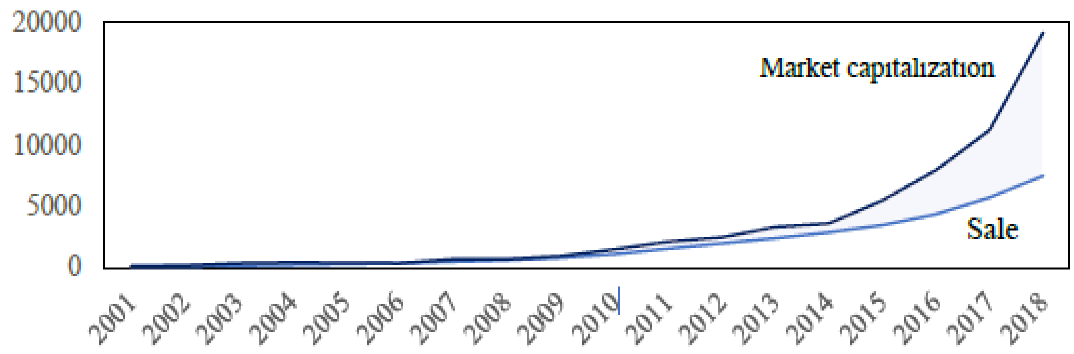


Figure 10. Trends in sales and market capitalization in Amazon (2001-2018) – Index: 2001 = 100.

Source: [4].

Table 2. The correlation between sales and market capitalization in Amazon (2001-2018).

$$\ln MC = \underset{(10.78)}{6.14} + \underset{(8.62)}{0.95}\, D_1 \ln S + \underset{(10.67)}{1.34}\, D_2 \ln + \underset{(2.38)}{1.48} D_1 \qquad DW\ 1.40 \quad adj.R^2\ 0.978$$

MC: market capitalization; *S*: sales.
D: dummy variables. D_1: 2001-2009 =1, others = 0; D_2: 2010-2018 = 1, others = 0.

The figures in parentheses indicate the t-statistics: all are significant at the 1% level.

Increase in gross R&D accelerates growth which activates self-propagating function by enhancing the carrying capacity. This triggers the above transformation. This is also demonstrated by the Amazon's conspicuous R&D-driven development trajectory as demonstrated in **Table 3**.

Table 3. The correlation between R&D investment and sales in Amazon (2001-2017).

$$\underset{}{\ln S} = \underset{(23.32)}{3.19} + \underset{(12.83)}{0.73}\, D_1 \ln R + \underset{(9.52)}{0.61}\, D_2 \ln R - \underset{(-2.34)}{0.36} D_1 \qquad DW\ 1.90 \quad adj.R^2\ 0.987$$

R: R&D investment.
D: dummy variables. D_1: 2001-2009 =1, others = 0; D_2: 2010-2017 = 1, others = 0.

The figures in parentheses indicate the t-statistics: all are significant at the 1% level.

The above transformation dynamism is illustrated in **Fig. 11**.

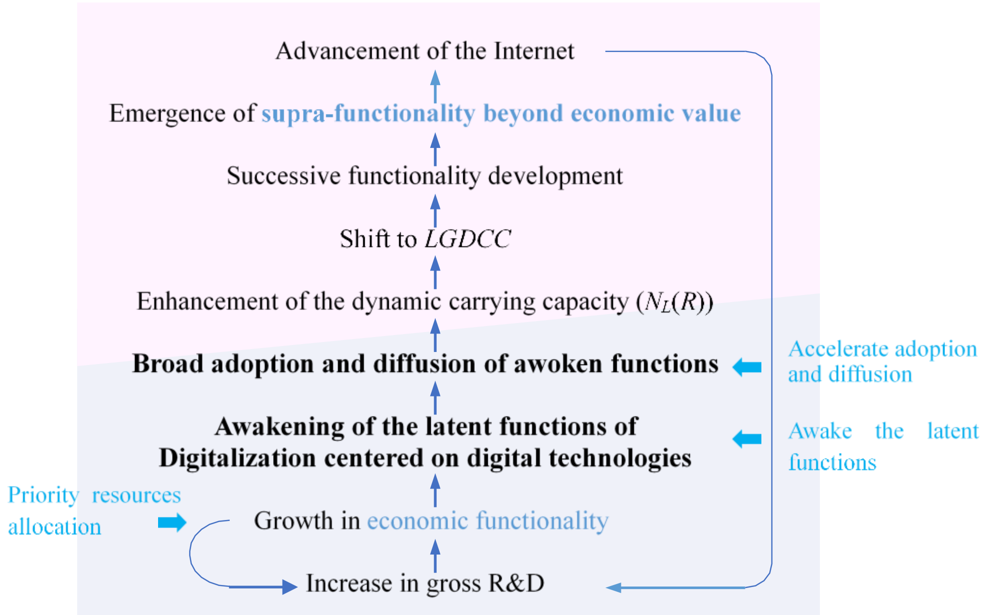


Figure 11. Dynamism in transforming economic functionality into supra-functionality.

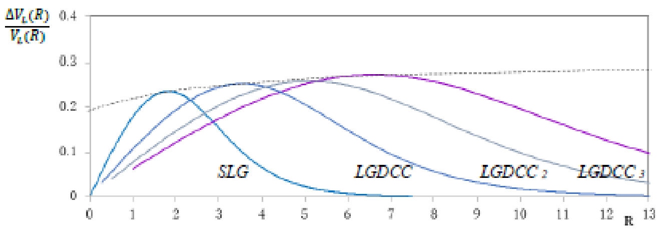
Actions highlighted in blue indicate policy actions for accelerating the transformation.

Since supra-functionality beyond an economic value led by the dynamically enhancing carrying capacity corresponds to people's preferences shift, digital values increase and further advancement of the Internet is induced which, in turn, awakes and activates *SIRs*. In this activation process, development trajectory transforms from the captured GDP-based co-evolution cycle into the uncaptured GDP-driven co-evolution cycle. This transformation can be attributed to the Internet function [23] which awakes and activates such innovation resources as *SIRs* that bridge economic functionality and supra-functionality beyond an economic value.

3.2. Co-Evolutionary Coupling

This dynamism demonstrates the significance of co-evolutionary coupling between captured GDP-based co-evolution and uncaptured GDP-driven co-evolution as reviewed in Fig. 5.

Based on these analyses, **Fig. 12** examines possible trends in growth rate by R&D in global ICT firms in 2016 depending on the degree of *LGDCC* function (see the details in Appendix 2).



$$V(R) = \frac{N}{1 + b\,e^{-aR}} \quad b e^{-aR} = \frac{1}{x}$$ (N: carrying capacity; a, b: coefficients)

Growth rate $\frac{\Delta V}{V} \approx (\rho + g)\frac{\partial V}{\partial R} \cdot \frac{R}{V} = (\rho + g) \cdot \frac{\ln bx}{1+x}$

ρ: rate of obsolescence of technology, g: R&D growth rate at the initial period.

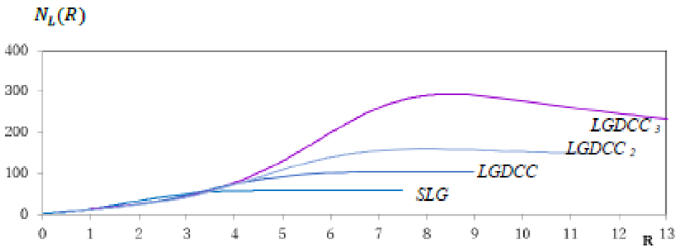
Gross R&D $R = R_i + z\ SIRs = R_i \left(1 + \frac{1}{1+\frac{\Delta SRIs/SRIs}{\Delta R_i/R_i}}\right) = R_i \cdot \phi$

R_i: indigenous R&D, $SIRs$: soft innovation resources, z: assimilation capacity.

Growth rate taking gross R&D $\frac{\Delta V}{V} \approx (\rho + g) \cdot \frac{\ln bx}{1+x} \cdot \phi$

Figure 12. Possible trends in growth rate by R&D in global ICT firms in 2016.

Utilizing the result of this analysis, **Fig. 13** examines the possible trends in the magnitude of the self-propagating function in global ICT firms in 2016 depending on the degree of *LGDCC* function as well as indigenous R&D (R_i) growth rate relative to that of *SIRs*. This demonstrates a synchronized co-evolutional cycle among, growth, $N_L(R)$, *LGDCC* and *SIRs*.



$$N_L(R) = V_L(R)\left(\frac{1}{1 - \frac{1}{a} \cdot \frac{\Delta V_L(R)}{V_L(R)}}\right)$$

$$= \frac{N}{1+\frac{1}{x}} \Bigg/ \left(1 - \frac{1}{a} \cdot (\rho + g) \cdot \frac{\ln bx}{1+x} \cdot \left(1 + \frac{1}{1 + \frac{\Delta SRIs/SRIs}{\Delta R_i/R_i}}\right)\right)$$

A case of $\frac{\Delta SRIs/SRIs}{\Delta R_i/R_i} = 0.5$

Figure 13. Possible trends in self-propagating function in global ICT firms in 2016.

3.3. Growth Trajectory Option

These analyses demonstrate the significance of co-evolutionary coupling between the captured GDP-based co-evolution cycle and the uncaptured GDP-driven co-evolution cycle. **Fig. 14** illustrates this coupling dynamism.

The captured GDP-based co-evolution induces the uncaptured GDP-driven co-evolution which, in turn, awakes and induces such innovation resources as *SIRs* that bridge both co-evolutions. Gross R&D consisting of indigenous R&D and assimilated external innovation resources centered on *SIRs* play a triggering role. Indigenous R&D is expanded by the development of the former co-evolution and also enabled to increase without the dilemma by the development of the latter co-evolution. Assimilated *SIRs* depend on awaking and inducement of *SIRs* attributing to the advancement of the Internet induced by the advancement of the latter co-evolution, and also assimilation capacity to which rapid and notable increase of indigenous R&D play a decisive role. Thus, well-balanced co-evolutionary coupling between the advancements in both co-evolution cycles is essential for sustainable growth in the digital economy in a long time future.

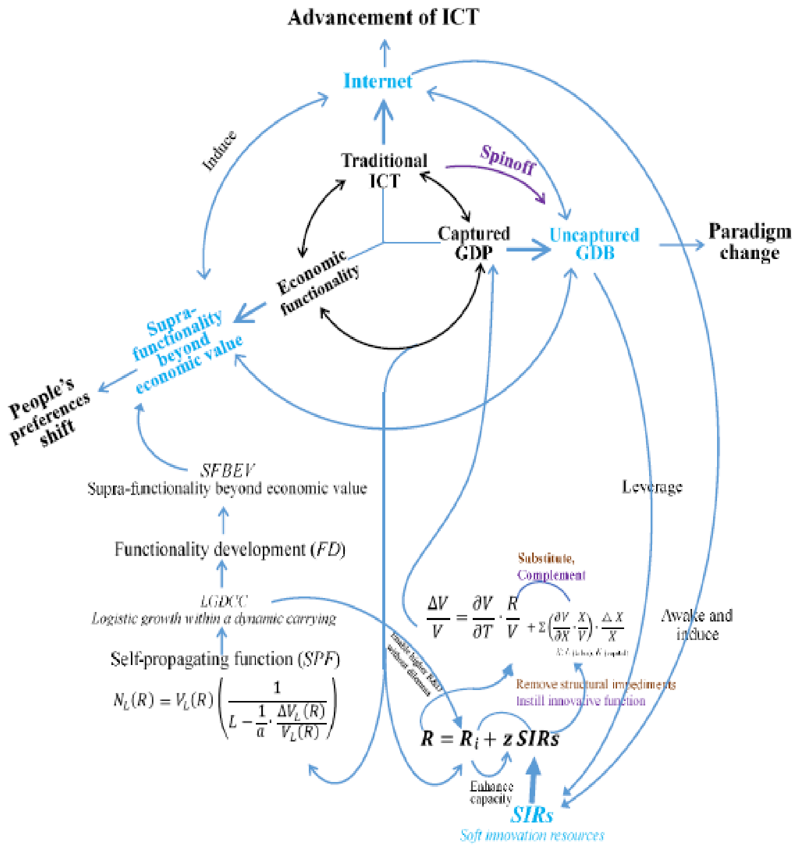


Figure 14. Co-evolutionary coupling between the captured GDP and the uncaptured GDP cycles.

Fig. 14 suggests that once the engine is fired up, a virtuous cycle can be expected. Therefore, deployment of such a function as turning on the ignition plays a decisive role.

Based on these analyses, **Table 4** and **Fig. 15** compares development dynamism depending on the growth trajectory option.

Table 4. Options of growth routes.

	Function	Innovation system	Trigger of innovation
SIRs-based resurgence option	Remove structural impediments in growth	Resurgence of stagnated captured GDP	Change in institutional systems
R&D-driven innovative growth option	Generate supra-functionality beyond economic vale	Co-evolution between the Internet, uncaptured GDP and supra-functionality beyond an economic value	Breakthrough by R&D

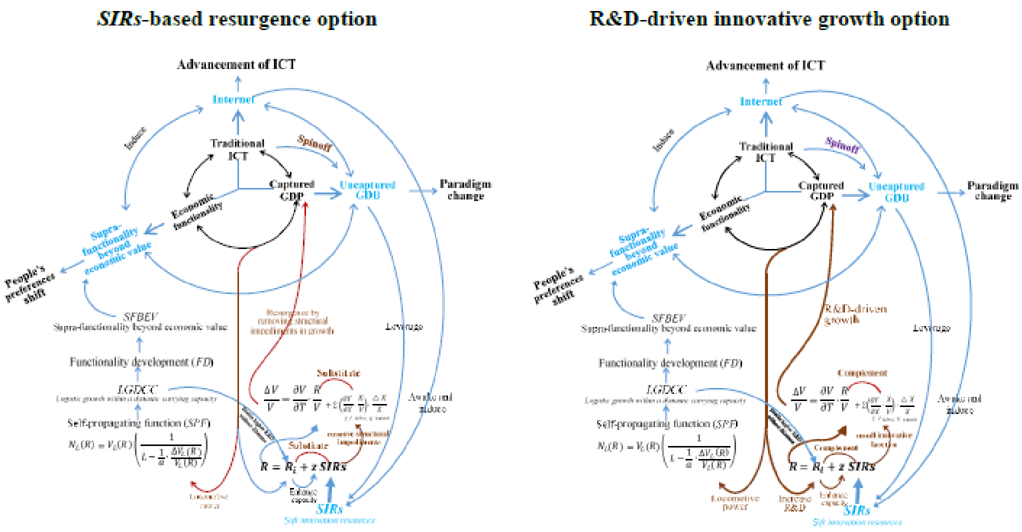
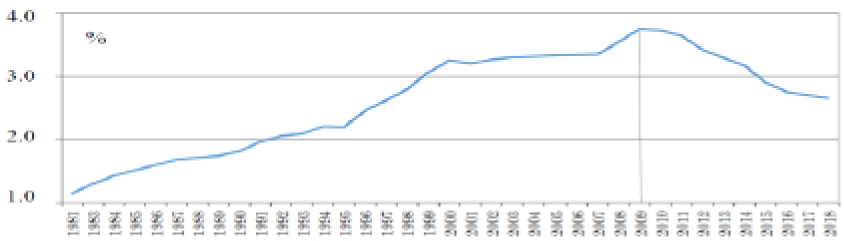


Figure 15. Comparison of growth trajectory options.

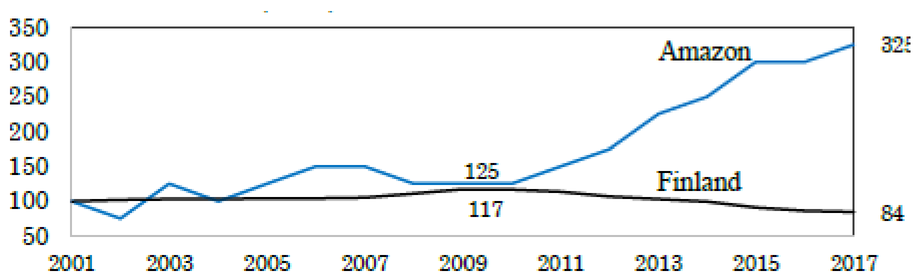
SIRs-based resurgence focuses on captured GDP growth by removing structural impediments in its growth. Finland’s recent resurgence is a typical endeavor. It attempted to remove structural impediments in tangible capital growth. *SIRs* substituted for R&D and spilled over to tangible capital thereby removed structural impediments in its growth that contributed to captured GDP growth [5].

R&D-driven innovative growth endeavors R&D-driven growth thereby utilizes the outcome of growth for further R&D inducement and also for locomotive power of the activation of the latent self-propagating function that leads to the LGDCC development.



Source: OECD (2018).

Figure 16. Trend in R&D intensity in Finland (1981-2018).



(2001-2017)- Index: 2001 = 100.
Source: [4, 26].

Figure 17. Trend in R&D intensity in Amazon and Finland

While Amazon has constructed complementary development of both options, since Finland had deployed the latter option earlier [10, 12] as demonstrated in Fig. 16, its recent notable resurgence can largely be attributed to the deployment of the former option [5]. Fig. 17 demonstrates the contrast in two leaders with respect to R&D investment initiative.

Based on these reviews **Fig. 18** examines a possible consequences of the growth trajectory option between *SIRs*-based resurgence option and R&D-driven innovative growth option by comparing the attainability of the self-propagating function.

Fig. 18 demonstrates that while the former option attains higher self-propagating function faster than the latter option, the latter option catches up with the level of the former as time passes and exceeds that level in a long run.

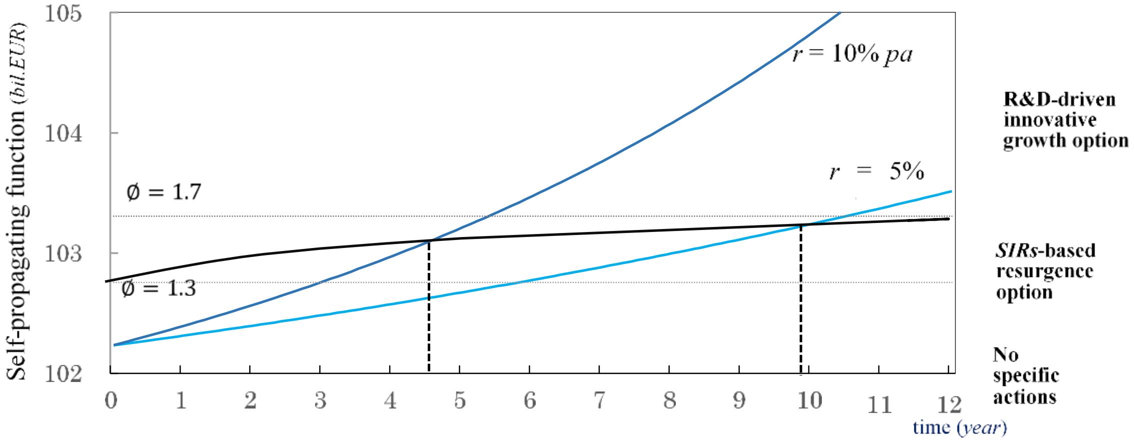


Figure 18. Possible consequences of the growth trajectory option (A case of the top 5th level global ICT leader in 2016).

Note Effects of the following R&D acceleration strategy taking a case of the top 5th level global ICT leader in 2016 were compared (R&D expenditure was around 10 billion Euro):

R&D acceleration strategy $R = R_i \cdot \chi$ R_i: indigenous R&D expenditure, χ: inducing intensity.

Self-propagating function under the R&D acceleration

$$N_L(R) = V_L(R)\left(\frac{1}{1-\frac{1}{a}\cdot\frac{\Delta V_L(R)}{V_L(R)}}\right) = \frac{N}{1+\frac{1}{x}} \Big/ \left(1-\frac{1}{a}\cdot(\bar{\rho}+g)\cdot\frac{\ln bx}{1+x}\cdot\chi\right)$$

R&D acceleration option

χ_0 No specific actions: $\chi = 1$

χ_1 *SIRs*-based resurgence option: $R = R_i + zSIRs = R_i\left(1+\frac{1}{1+\frac{\Delta SRIs/SRIs}{\Delta R_i/R_i}}\right) \equiv R_i \cdot \phi \quad \chi_1 = \phi = \left(1+\frac{1}{1+\frac{\Delta SRIs/SRIs}{\Delta R_i/R_i}}\right)$

χ_2 R&D-driven innovative growth option: $R_t = R_i(1+r)^t$ $\chi_2 = (1+r)^t$ r: increase rate, t: time

Based on the empirical reviews of the strategic actions undertaken by highly-R&D intensive global ICT firms in 2016, following growth rate on *SIRs* and R_i were examined (figures indicate the value of ϕ):

SIRs \ R_i	5 % *pa*	10 % *pa*
5 % *pa*	1.5	1.67
10 % *pa*	1.33	1.5

*1 Arrow indicates a plausible direction.
*2 While change in R_i effects to x, its increase reacts to increases in R, V, and $N_L(R)$, leading to further advantage in R&D-driven innovative growth option.

4. CROSS LEARNING

4.1. Co-Evolutionary Complement

As reviewed in the preceding section, the disruptive business model initiated by global ICT leaders for solving the dilemma between R&D expansion and productivity decline can be traced by two co-evolution cycles. While both global ICT leaders, Amazon and Finland have demonstrated conspicuous contributions to respective cycle [3, 5], Finland's approach, notwithstanding its smart resurgence, casts a shadow to the innovative growth in the future (Tou et al., 2019*c*). Analysis in the preceding section endorses this fear. This resurgence based on *SIRs* substitution for gross service capital (GSC, centered on R&D), and *SIRs* spilled over to gross tangible capital (GTC) thereby removed structural impediments in its growth. **Table 5** re-examines Finland's approach.

Table 5. Transformation of components of gross capital in the digital economy in Finland.

Traditional classification	GSC	GTC
Environmental change	Increasing difficulties, uncertainties, lengthy pregnant period, and expenditures	Availability of practical platform effects, package software
Firms/nations behavior	Escape from difficulties	Depending on easy solution
National Accounting	Decreasing share after 2010	Increasing share after 2010 (GTC substitutes for GSC)
Transformation of functions	Losing innovation function	Gaining innovation function
Effects	Losing timely significant breakthrough opportunity	Contribute to resurgence

Original Source: [8].

While this approach enables prompt outcomes without heavy burdens and strong risks, it loses timely significant breakthrough opportunities which may result in non-sustainable growth in the future as estimated in Fig. 18. IMF's recent reserved prospect on Finland's GDP growth toward 2023 (IMF, 2019) corresponds to this fear. It forecasted Finland's average real GDP growth rate over the period from 2019-2023 1.40% *p.a.*, the lowest after Japan among 11 leading countries. This is a clear contrast with that of 2016-2018 as 2.64 % *p.a.*, the highest after Singapore.
Contrary to such fear in Finland, Amazon has constructed a robust model by means of co-evolutionary coupling between two co-evolutions as demonstrated in **Fig. 19** [3].

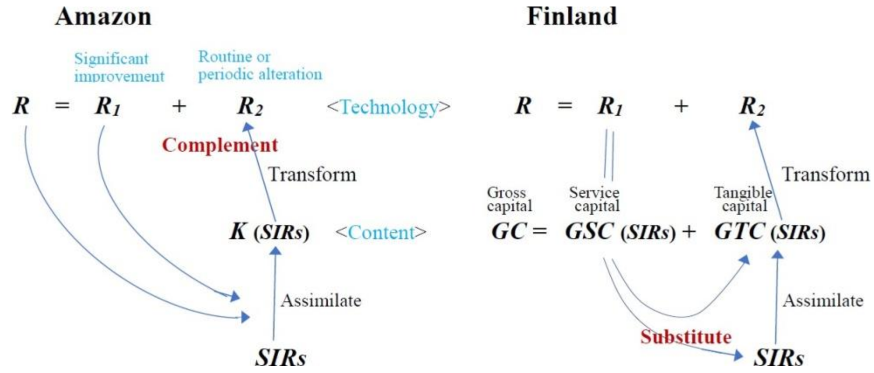


Figure 19. Similarity and disparity of R&D model between Amazon and Finland.
Original Source: [3].

4.2. Cross Learning

Based on its unique R&D model, Amazon has jumped up to the world's top R&D firm in 2017 by complementing "significant improvement" endeavors and "routine or periodic alterations" endeavors (Amazon describes its R&D as "technology and content" in its annual report, the former corresponds to "significant improvement," and the latter to "routine or periodic alterations"). The latter endeavors have been transformed into the former during the course of innovation endeavor by absorbing *SIRs* in the marketplace and assimilating them to its business [3].

Amazon, which is based on R&D as a culture [27], has been promoting companywide experimentation to cause customers obsessed with making purchase decisions. This has enabled Amazon to deploy an architecture for participation that makes the most of digital technologies by harnessing the power of users [28]. Such user-driven innovation accelerated a dramatic advancement of the Internet that, in turn, accelerated the co-emergence of *SIRs* in the marketplace. This emergence activated a self-propagating function that induced functionality development, leading to supra-functionality beyond an economic value that satisfies a shift in customers' preferences, which Amazon has been treating as the highest priority. Since this system depends on the assimilation capacity of *SIRs*, Amazon has developed a high level of capacity, supported by a rapid and notable increase in R&D investment [29]. Such a sophisticated management system has operated well because of strong inertia induced by the strongly customer-centric visionary leadership of Jeff Bezos (founder and CEO of Amazon), together with motivated, brilliant and consistently innovative employees equipped with species survival and an evolution system that watches for the necessity of disruptive business change [30]. These efforts function co-evolutionally, leading to the transformation of "routine or periodic alterations" into "significant improvement."

Thus, Amazon has succeeded in constructing co-evolutionary coupling between the captured GDP-based co-evolution cycle and the uncaptured GDP-driven co-evolution cycle as illustrated in Fig. 14 in multi-layer levels.

While the transformation of the captured GDP-based co-evolution cycle into the uncaptured GDP-driven co-evolution cycle could result in new monopoly [31], such monopoly should be avoided by developing strong competitive powers, not regulating neither dividing winners [32].

In this context, Finland's success, triggered by the enactment of the Competitiveness Pact in 2016, through exploring elastic labor supply, fostering a trusting relationship between employer and employees, satisfying on demand supply and transgenerational preferences towards an aging society [5] may provide Amazon an insightful suggestion for solving its critical problems with respect to consensus gaining among stakeholders, instilling confidence in employees, and also to corresponding to new monopoly issues. This corresponds to such endeavors as coupling the two co-evolution cycles. By this coupling, the above strong transformation power, which is feared to emerge new monopoly, may be utilized for exploring new platform ecosystem beyond new monopoly.

Therefore, it can be concluded that cross learning among global leaders lead to successful co-evolutional coupling between captured and uncaptured GDP cycles that transforms the dilemma into a new innovation emergence.

5. CONCLUSION

A dilemma between R&D expansion and productivity decline has become the critical problem that a majority of ICT leaders have been confronting in the digital economy. While a solution to this problem can be expected by a spinoff from economic functionality-seeking GDP-based co-evolution cycle to supra-functionality beyond an economic value-seeking uncaptured GDP-driven co-evolutional cycle, its transformation dynamism remains a black box.

By means of numerical simulations based on empirical analyses of the development trajectories of global ICT leaders, focusing on Amazon and Finland, together with an intensive review of preceding analyses, this paper attempted to elucidate this dynamism.

By developing a practically applicable numerical approach, inspired attempts to explore a new elucidation frontier were conducted, thereby a new concept of co-evolutionary coupling between two cycles was postulated.

This postulate identified two development trajectories option: *SIRs*-based resurgence option and R&D-driven innovative growth option.

SIRs-based resurgence focuses on captured GDP growth by removing structural impediments in its growth. Finland's recent resurgence is a typical endeavor.

R&D-driven innovative growth option attempts R&D-driven growth thereby utilizes growth for further R&D inducement and also for locomotive power of the activation of the latent self-propagating function that leads to the *LGDCC* development

While Amazon has constructed complementary development of both options, Finland's recent notable resurgence can largely be attributed to the deployment of the former option as it had deployed the latter option earlier.

While this approach contributed to easy resurgence, it may lose timely significant breakthrough opportunity expected to be initiated by R&D. This lost is feared to cancel the success in resurgence in the future.

In order to avoid such a fear, it is strongly required to endeavor comprehensive strategy for the future that accelerates (i) priority resources allocation, (ii) awakening the latent function of digitalization centered on digital technologies, and (iii) adoption and diffusion of awoken function. Effective combination of financial, regulatory, and also educational policy tools that corresponds to an IoT society should be devised.

While the transformation of the captured GDP-based co-evolution cycle into the uncaptured GDP-driven co-evolution cycle could result in new monopoly, such monopoly should be avoided by

developing strong competitive powers, not regulating neither dividing winners.
In this context, Finland's success, triggered by the enactment of the Competitiveness Pact in 2016, through exploring elastic labor supply, fostering a trusting relationship between employer and employees, satisfying on demand supply and transgenerational preferences towards an aging society may provide Amazon an insightful suggestion for solving its critical problems with respect to consensus gaining among stakeholders, instilling confidence in employees, and also to corresponding to new monopoly issues.

Thus, cross learning among global leaders lead to successful co-evolutional coupling between captured and uncaptured GDP cycles that transforms the dilemma into a new innovation emergence.

Future work should focus on accrual of these cross learning to general policy ecosystems.

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APPENDIX 1

BASIC STATISTICS FOR THE ANALYSIS

Table A1 Trends in sales, market capitalization and R&D expenditure in Amazon.

Sales	(billion USD)	Market Capitalization (billion USD)	R&D expenditure (billion USD)
2001	3.12	4226	0.1
2002	3.93	6294	0.1
2003	5.26	15354	0.3
2004	6.92	17515	0.3
2005	8.49	16517	0.5
2006	10.71	15107	0.7
2007	14.84	28871	0.8
2008	19.17	28946	1
2009	24.51	39053	1.2
2010	34.20	61931	1.7
2011	48.08	88631	2.9
2012	61.09	102698	4.6
2013	74.45	138486	6.6
2014	88.99	150695	9.3
2015	107.01	230437	12.5
2016	135.99	334432	16.9
2017	177.87	472592	22.6
2018	232.89	806964	-

Source: [4].

APPENDIX 2

ESTIMATION OF DEVELOPMENT TRAJECTORY

1. Mathematical Development

Digital value V created in an IoT society can be depicted as follows [13, 14]:

$$V = F(X, T) = F(X(T), T) \approx F(T) \qquad \text{Growth rate: } \frac{\Delta V}{V} = \left(\frac{\partial V}{\partial T} \cdot \frac{T}{V}\right) \cdot \frac{\Delta T}{T} \approx \frac{\partial V}{\partial T} \cdot \frac{R}{V} \tag{A1}$$

where T: gross ICT stock; X: other production factors; and R: R&D investment ($\Delta T \approx R$).

In long run, since $T \approx \frac{R}{\rho+g}$, growth rate can be depicted as follows:

$$\frac{\Delta V}{V} = \frac{\partial V}{\partial T} \cdot \frac{R}{V} = \frac{\partial V}{\partial R} \cdot \frac{\partial R}{\partial T} \cdot \frac{R}{V} = (\rho + g)\frac{\partial V}{\partial R} \cdot \frac{R}{V} \tag{A2}$$

where ρ: rate of obsolescence of technology, g: R&D growth rate at the initial period.

Given the logistic growth nature of ICT, R&D-driven development trajectory $V_s(R)$ can be depicted by the following epidemic function that leads a simple logistic growth function (SLG):

$$\frac{dV}{dR} \approx \frac{\partial V}{\partial R} = aV\left(1 - \frac{V}{N}\right) \tag{A3}$$

$$SLG \quad V_s(R) = \frac{N}{1 + b\, e^{-aR}} \tag{A4}$$

where N: carrying capacity; a: velocity of diffusion; b: coefficient indicating the initial level of diffusion.

In particular innovation which creates new carrying capacity $N_L(R)$ during the process of diffusion, equation (A3) is developed as follows:

$$\frac{dV(R)}{dR} = aV(R)\left(1 - \frac{V(R)}{N(R)}\right) \tag{A5}$$

Equation (A5) develops the following logistic growth within a dynamic carrying capacity function ($LGDCC$) which incorporates self-propagating function as carrying capacity increases corresponding to $V(R)$ increase as depicted in equation (A6) [19]:

$$V_L(R) = \frac{N_k}{1 + be^{-aR} + \frac{b_k}{1 - a_k/a} e^{-a_k R}} \tag{A6}$$

$$N_L(R) = V_L(R)\left(\frac{1}{1 - \frac{1}{a}\frac{\Delta V_L(R)}{V_L(R)}}\right) \quad \Delta V_L(R) = \frac{dV_L(R)}{dR} \tag{A7}$$

where N_k: carrying capacity; a, b, a_k, and b_k: coefficients.

The LGDCC function by equation (A6) can be approximated by the following SLG function [33]:

$$V_L(R) = \frac{N_k}{1 + be^{-aR} + \frac{b_k}{1 - a_k/a} e^{-a_k R}} \approx \frac{N_k}{1 + b' e^{-a' R}} \quad a' = a\left(1 - \frac{b_k}{b}\right),\ b' = b\left(1 + \frac{b_k}{b} \cdot \frac{1}{1 - \frac{a_k}{a}}\right) \tag{A8}$$

Empirical Analysis

R&D-driven development trajectory of 500 global ICT firms in 2016 can be demonstrated as follows:

Table A2. Development trajectory of 500 global ICT firms in 2016.

	N	*a*	*b*	a_k	b_k	ln *b*/*a*	*adj.* R^2
SLG	59.62 (17.39)	1.32 (10.98)	15.91 (21.87)			2.10	0.784
LGDCC	102.23 (178.83)	0.77 (26.13)	15.84 (9.72)	0.43 (7.06)	1.32 (2.53)		0.999
LGDCC (approx.)	102.23	0.71	18.83			4.16	
LGDCC 2	140.00	0.50	20.00			5.99	
LGDCC 3	200.00	0.40	23.00			7.85	

The figures in parentheses indicate the t-statistics: all are significant at the 1% level.

LGDCC 2 and *LGDCC 3* are simulations.

Utilizing the results of the empirical analysis, above trajectory can be practically traced as follows:

$$be^{-aR} \equiv \frac{1}{x}, \text{Digital value } V = \frac{N}{1+\frac{1}{x}}; \text{ R\&D expenditure } R = \frac{\ln bx}{a}; \text{ R\&D intensity } \frac{R}{V} = \frac{\ln bx\,(1+x)}{aN \cdot x};$$

$$\text{Marginal productivity of R\&D } \frac{\partial V}{\partial R} = \frac{aN \cdot x}{(1+x)^2}; \text{ Growth rate } \frac{\Delta V}{V} \approx (\rho+g)\frac{\partial V}{\partial R} \cdot \frac{R}{V} = (\rho+g) \cdot \frac{\ln bx}{1+x};$$

$$\text{Gross R\&D} \quad R = R_i + z\ SIRs = R_i\left(1+\frac{1}{1+\frac{\Delta SRIs/SRIs}{\Delta R_i/R_i}}\right) \equiv R_i \cdot \phi, \ \ \phi = \left(1+\frac{1}{1+\frac{\Delta SRIs/SRIs}{\Delta R_i/R_i}}\right);$$

$$\text{Self}-\text{propagating function } N_L(R) = V_L(R)\left(\frac{1}{1-\frac{1}{a}\frac{\Delta V_L(R)}{V_L(R)}}\right) = \frac{N}{1+\frac{1}{x}} \Big/ \left(1-\frac{1}{a} \cdot (\rho+g) \cdot \frac{\ln bx}{1+x} \cdot \phi\right) \tag{A9}$$

where R_i : indigenous R&D; SIRs: soft innovation resources; z: assimilation capacity.

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